the perpendicular downwards to cut the valve circle. This angle is less than 180°, the period for the valve without lap.

In fig. 15 *b* the eccentric circle is drawn to an enlarged scale. Suppose *cj>* is the angle that the eccentric crank makes with the line of stroke of the engine and ?// the angle that the main crank makes with the same initial line, then

$$cf> = 90 + a + 0,$$

where a is the angle of advance, i.e. the angle YOX_X of fig. 15 *a.* Hence

$$</> — (90 + a) = \ ^$$

i.e. if we rotate the valve diagram, giving the position of the eccentric, backwards through an angle (90 + <*)> the new diagram gives the positions of the main crank at the corresponding valve positions. Now rotate the valve diagram (fig. 150) so that OX_X is rotated backwards through an angle (90 + <*)• The figure now obtained is shown in fig. 15 Z>, where X_x gives the direction of the *main crank* at the valve positions corresponding to X_x in fig. 15 <z, i.e. OX_X in fig. 156 gives the direction of the crank at admission. Suppose now the angle XiOCj is set off equal to */3,* then OC^ in fig. 156 gives the direction of the crank corresponding to valve-position OC_X in fig. i5<2. Now, if the connecting-rod is very long, we can drop Cj^ perpendicular to OX, and 0^ gives the displacement of the piston from its mean position.

In order to assist in bringing the moving parts to rest, especially in quick-running engines, some form of " cushioning " must be provided. Such a steam cushion could obviously be provided if the connection from the cylinder space at the back of the piston to the exhaust pipe were closed a little before the piston had reached the dead centre on the exhaust stroke. All that is necessary to bring about this state of things is to provide *inside* or *exhaust lap* on the valve as is shown in fig. 14, marked *i.*

It is also desirable that the valve admitting " live steam " to the back of the piston should be open to a certain extent when the piston crosses the dead centre. This effect is brought about by slightly increasing the angle of advance, so that the valve is displaced a little more than it

normally would be, when the piston is at the dead centre. The effect of this is, of course, to open the port slightly before the piston has reached the dead centre, so that *pre-admission* occurs. The amount by which the port is open when the crank is actually on the dead centre is called the *lead,* and it varies in amount with the type and speed of the engine. A very simple relation connects the quantities, outside lap, lead, throw of valve, and angle of advance. It is

$$e + l = r \sin \#,$$

where e is the outside lap, l the lead, r the throw of the eccentric, and 9 the angle of advance, that is, the normal angle of advance a plus the increment which must be provided to secure the lead. The total angle of advance 6